

Applications of Fibrous Technologies for Environment and Resource Matters

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Abstract

In this paper, it is tried to give an overview on application technologies using fibrous materials contributing to environmental and resource matters, such as i) thermal insulations, ii) parts of energy devices, iii) elements related to energy sources, iv) lightening of transportation vehicles, v) energy saving through clothing, bed clothing, interior and exterior, vi) water treatment and purified water production, vii) separation between oil and water, viii) air purification, ix) enclosure of contaminated substances.

Keywords

Fibrous Technologies; Environment; Resource Matters; Applications

Introduction

Problems of global environment and resources have become one of the most serious issues for our human race. On the other hand, there is a big space for fiber and textile technologies to contribute toward these problems meaning that there can be a big business opportunity for fiber/textile industry. The individual field in the technological opportunity must be categorized as follows;

- 1) technology field for the attenuation of global warming,
- 2) technology field for the reduction of global contamination, and
- 3) technology field for the attenuation of resource problems

It is also thought that the technologies can be conveniently classified into the defensive technologies and the offensive technologies from the view point of fiber/textile. The formers are those which can contribute to reduce the loads caused by the textile industry on global environment and resources. The offensive technologies are those which can contribute to reduce the loads originating from the other kinds of industries than textile industry, and human livings/

activities. Such technologies as i) bio-degradable fibers, ii) fibers/ textiles made with low energy consumption and no environmentally harmful exhaust substances, iii) recycle systems of textile wastes, iv) waste reduction and energy saving at fiber plants /textile mills, v) treatment of wastes at fiber plants and textile mills and vi) re-use and recycle of textile products can be classified as defensive. On the other hand, the offensive technologies include the applications of fibrous materials to the following items; i) thermal insulations, ii) parts of energy devices, iii) elements related to energy sources, iv) lightening of transportation vehicles, v) energy saving through clothing, interior, bed-clothing, and exterior, vi) water treatment and purified water production, vii) separation between oil and water, viii) air purification, ix) enclosure of contaminated substances.

In this paper, the offensive technologies related to the above-mentioned items from i) to ix) are overviewed.

Applications to Thermal Insulation

Glass wool is widely used as insulation material especially in the field of house outer wall, floor and roof. For high heat resistant thermal insulation, such insulation sheet as basalt fiber, non-crysatal ceramics fiber, alumina fiber is used depending on the required heat resistance performance and cost.

Vacuum insulation sheet whose insulation performance is about 25 times higher than glass wool has been recently developed. The sheet is composed of multi-layered film containing a metallized layer and glass wool packaged as a core material in vacuum state. It is firstly used as non-fron insulator for refrigerator. Now its application is widened in such field as house floor, outer wall, and vending machine.

Roof shade suitably made of woven fabrics for house can effectively cut the radiation energy of sun light, by which the energy load of its air conditioning can be reduced.

Applications to Energy Devices

Nickel Metal Hydrate Battery (NiMHB)

In the application to portable instruments, NiMHB has been mostly replaced by LIB described in the next section, which has higher capability in energy density. But because of its higher reliability for safety, NiMHB has been still used for HEV of Toyota and Honda.

The separator of NiMHB is usually made of thermal bonded poly-olefine fiber nonwoven to which hydrophilic treatment through sulfonation was applied. It is desirable that the fiber is finer and has higher strength and that the nonwoven is thin and highly uniform.

Li-ion Rechargeable Battery (LIB)

The most significant feature of LIB is that it can have much higher energy density than conventional batteries. It has also an excellent holding ability of charged energy. Hence LIB has been widely applied to portable electronic instrument such as telephone since around 1996.

LIB is now strongly expected that it must become safer, more economical, lighter, and also has longer life and wider material supply source to be the electric power storage for EV/PHEV and solar cell /wind power. Then very competitive developmental activities for this goal have been now carried out in the world.

In order to increase the mobility of electron, linear form electro-conductive fillers by which can connect active material particles each other are used, as shown in Fig.1. The filler is usually acetylene black which takes a linear form by the connections. But for high quality battery, carbon nano-fiber(MWCNT) is used instead of such an acetylene black. MWCNT is also effective for the improvement of dimensional stability and electric conductivity of the cathode by its bridging among graphite particles.

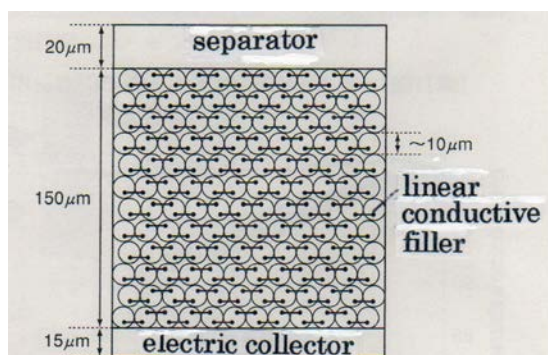


FIG. 1 SCHEMATIC STRUCTURE OF LIB ANODE AND THE ROLE OF LINEAR CONDUCTIVE FILLER

Fig.2 is the cross-sectional view showing the bridging by MWCNT. Fig.3 shows that the life of LIB can be much improved by the 10% addition of VGCF (vapor grown MWCNT) to the cathode.

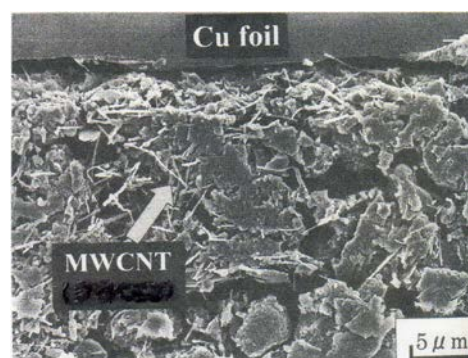


FIG. 2 BRIDGING OF GRAPHITE PARTICLES BY MWCNT IN THE CATHODE OF LIB

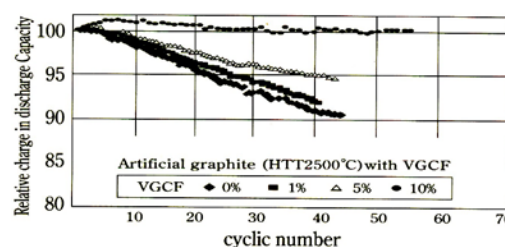


FIG. 3 THE EFFECT OF MWCNT BRIDGING WITHIN THE CATHODE ON THE IMPROVEMENT IN THE LIFE OF LIB

The main function required for LIB separator are i) the holding of electric insulation and ii) high ability in Li-ion wet-ability and its transfer. LIB separator is typically nano-porous membrane made of high molecular weight polyethylene. The pore diameter is about 50nm. It has high capability to prevent the growth of Li-dendrite. It has also high capability of shutting down its pores at over-heated state for safety. But now the requirement of higher temperature resistance has been increased for high power application such as EV. In this situation, several types of higher temperature resistance has been developed, such as a) nano-fiber nonwoven coated by ceramic particles, and b) nonwoven made of high strength , high heat resistance nano-fiber.

Fuel Cell

Fuel cell can be classified into the following four types by the material of electrolyte; i) proton exchange membrane type (PEFC), ii) phosphoric acid type, iii) molten carbonate types, and iv) solid oxide type. The type of fuel cell for automotive use and home use is usually PEFC.

The power generation efficiency of PEFC is almost at the same level as that of thermal power generation.

But in the case that its exhaust heat is effectively utilized, its total efficiency can be above 80%.

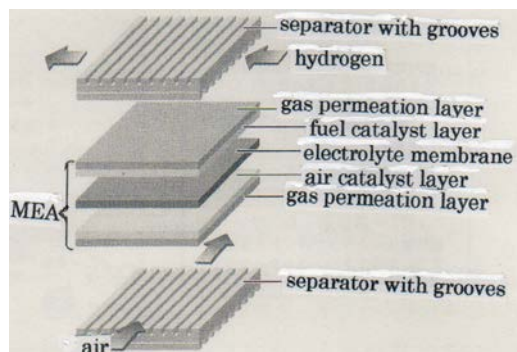


FIG. 4 STRUCTURE OF A UNIT CELL IN PEFC

The unit cell structure of PEFC is illustrated in Fig.4. At the each side of the separator, there are grooves through which air or hydrogen is supplied to MEA (see Fig.4). The center of the separator is electric insulation layer. The layers at the both sides of the insulation layer are so electro-conductive that they can work as power collectors. In MEA, proton exchange membrane electrolyte layer is laminated with fuel gas permeation-gas catalyst layer on the one side and with air permeation-catalyst on the other side. Both gas permeation and air permeation layers are usually made of carbon fiber/carbon matrix porous paper, because it has high gas permeability, high electric conductivity, to be thin, high flatness, high corrosion resistance and excellent tenacity. The voltage of the unit cell is about 0.6V. Then fuel cell is consisted of the serial stack of many unit cells.

The problem of fuel cell in common is that its equipment is still to be too expensive. Pt is usually used for the catalyst. This is one of the biggest factors for such a high cost. Hence much effort to develop less expensive catalyst has been paid in the world. On the other hand, several trials to improve the catalyst reaction efficiency have been done. It must be noticeable that carbon nano-tube of cup stack type(CS-CNT) can be a hopeful candidate as good carrier of the catalyst.

Now Nafion membrane made of fluoro-polymer is usually used because of its high proton permeability. But Nafion membrane is also expensive. Now several kinds of less expensive and higher temperature resistance membranes have been also tried. One of the trial examples is the membrane composed of nano-fiber made of sulfonated block co-polyamide.

Sodium-sulfur Battery(SSB)

The cathode and the anode of SSB is liquid sodium and

liquid sulfur, respectively, whose electrolyte is a specific ceramic such as β -aluminum. Its working temperature is about 300°C. Liquid sulfur is separated from liquid sodium by the ceramic membrane. Carbon fiber is used for the electrical conductivity of the anode. Graphite nano-fiber may be essentially more feasible.

As compared with lead-acid battery, the storage capacity of SSB in energy density is about 3 times. Self-discharge at SSB is effectively blocked by the ceramic membrane. The efficiency of charging and discharging at SSB is excellently high. The life of charging and discharging cycle is above 2000.

SSB is now going to be introduced for the storage of night power and for the attenuation in power fluctuation caused by natural regenerative power such as solar battery and wind turbine.

Next Generation Super Capacitor

Electric double layer capacitor(EDLC) using activated carbon is usually called as super capacitor. Electric double layer is the phenomenon of the electric charge distribution at the inter-surface between liquid and solid in which ion layer in liquid dielectrically faces to ion layer in solid. Fig.5 shows the position for several kinds of energy devices in power density and energy density. Recently a few kinds of next generation super capacitors have been developed using CNT or carbon nano-fiber, which can sufficiently achieve the required performance of energy recovery systems for several kinds of driving application as shown in the figure.

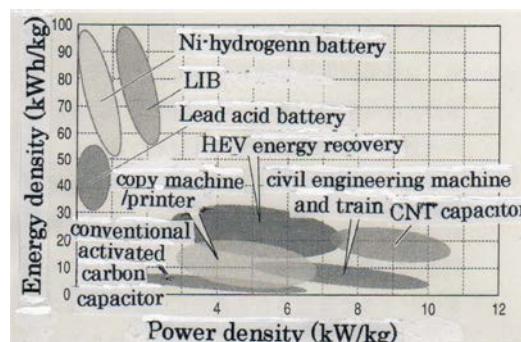


FIG. 5 THE POSITIONS OF SEVERAL KINDS OF ENERGY DEVICES IN POWER DENSITY AND ENERGY DENSITY

Super Conducting Magnetic Energy Storage (SMES)

SMES consists of super conducting coils, cryostat which contains the coils and AC/DC converter. Energy can be stored by applying DC current to the coils and then by switching off. The energy thus stored can be used as AC power through the converter. The power storage and supply can semi-permanently work by switching off and on.

The coil is composed of super conducting wire wound on a bobbin made of fiber reinforced plastic composite. Ultra-high molecular PE fiber is usually used as the reinforcing fiber. Because its thermal axial expansion coefficient is sufficiently minus, the tightness between the bobbin and the wire can be kept at the cryostat temperature.

Applications to Generation of Electric Power, to Fuel Vessels, and to Power Supply System

Wind Turbin Blade

The turbin blade of wind power is usually made of plastic reinforced by continuous carbon fiber and glass fiber. Recently the size of blade has increased even above 100m and its generation capacity can be 3-5MW. Its power cost can be reduced to the same level as that of thermal power generation plant. The world total generation capacity of wind power has increased and is expected significantly to increase.

High Pressure Gas Vessel

As the container of gas such as hydrogen and natural gas, high pressure gas vessel made of carbon fiber reinforced composite has been developed, and applied to fuel cell car, fuel tank for bus and truck, which is effective to decrease CO₂ exhaust amount.

Tension Member for Transmission Cable

In developing countries, the demand for constructing new transmission cable line has expanded with an increase of electric power consumption. Smart grid system also raises the demand of new cableline. In order to efficiently construct the line, the high voltage cable is desired to be less sagging, and of high transmission capacity. Then the demand for composite core cable has been increased. High performance fiber such as carbon fiber and p-aramid fiber is used for its reinforcement.

Applications to Lightening Transportation Vehicles

The share of transportation in the world CO₂ exhaust amount is about 23%. The exhaust is mostly carried out at the transport working stage of the vehicle in its life-cycle. Hence lightening transportation vehicle such as air-craft and automobile is effective to decrease their working energy consumption.

When weight reduction effect by panel made of several materials under the same stiffness is compared

to steel panel, glass fiber reinforced plastic (SMC) is lighter by 40%. It is noticed that carbon fiber reinforced plastic composite (CFRP) can be lighter by 67%.

Air-craft

(Energy consumption/distance) is one of the most important performances required for commercial aircraft. Hence a high amount of effort has been done to reduce its body weight. Application of carbon fiber reinforced plastic composites to its primary structures has made much progress by improving their toughness. Now, B787 and A350 whose CFR composite ratio by weight is about 50% is in commercial aviation and is going to be commercial aviation, respectively. Fig.6 shows materials used for the body of B787.

The toughness can be conveniently measured by inter-layer shear strength (ILSS). There are several ways to enhance ILSS such as i) introduction of toughening particles into matrix resin, ii) suitable insertion of reinforcing fiber oriented in thickness direction.



FIG. 6 MATERIALS USED FOR BOEING B787

Automobile

In the case of automobiles, many metallic parts such as bumper beam, engine cover, battery bracket, front end, and underbody shield have been objective parts to be replaced by glass fiber reinforced plastics. Fig.7 shows an example of such replacements. The intake-manifold shown in the figure was fabricated by the combination of injection molding and ultrasonic adhesion, whose weight reduction ratio is 40% from the previous aluminum part.

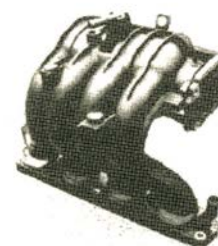


FIG.7 AN EXAMPLE OF AUTOMOTIVE PARTS MADE OF GLASS FIBER REINFORCED PLASTIC

On the other hand, the applications of CFRP to automobiles have been mainly limited to such parts as some parts of chassis for many high class sport cars and propeller shaft for high and middle class cars. The propeller shaft made of CFRP takes advantages over metallic shaft not only in weight reduction but also in higher safety at collision, and in higher vibration damping. Fig.8 shows CFRP parts related to the cabin and frame of LEXAS LFA.

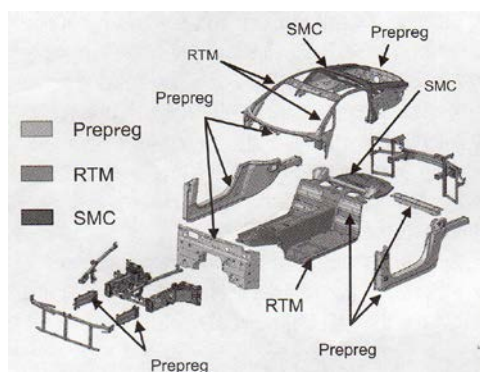


FIG.8 CFRP PARTS RELATED TO THE CABIN AND FRAME OF LEXAS LFA

The regulation in the world for car fuel consumption ratio by running distance tends to be more severe. In this connection, several projects to cope with the regulation have been carried out in such countries as USA, EU and Japan. One of the most important problems in these projects is how to realize weight reduction with reasonable cost for popular cars. In the NEDO project carried out in Japan during the period from 2003-2007 for car weight reduction through the use of CFRP, the technologies by which 40% weight reduction ratio as compared with steel parts have been developed. In the technologies, advanced CFRP parts can be fabricated within 10 mins which can be applicable to middle class cars, but exclusive to popular cars, because fabrication cycle is still too long. For manufacturing popular cars, the cycle must be at the level of 1min. In addition, the material recycle of the parts must be possible. Then the projects in which the application of carbon fiber reinforced thermoplastic composites to cars is now going on.

Energy Saving Through Clothing, Bedcloth, Interior and Exterior

Energy for air conditioning can be saved to some extent through using suitable textile products. Since 2006, Japan government has initiated such campaign in which the suitable clothing is called as "cool biz" for summer season and "warm biz" for winter season. In the campaign, recommended room temperature is 28°C and 20°C, respectively. Consequently "cool biz"

and "warm biz" have been well penetrated in Japan.

Along this movement, many kinds of new textile goods in such fields as clothing, interior and bed clothing have been commercialized. For examples, some kinds of fabrics giving cool touch feeling have been commercialized, in which larger amount of heat transferred from human skin to fabric is realized. Saving the energy for air conditioning can be also realized by adopting textile interior and exterior. These goods can cut the radiation energy of sunlight and can be effective thermal insulators between indoor and out-door.

Recently, a shelter system for truck driver using textile bag has been developed, in which conditioned air is circulated. By using the shelter, idling of truck during the rest/sleeping time of driver can be avoided.

Water Treatments and Purified Water Production

Water Treatments by Filtration, and by Bio-reaction Using Fibrous Materials

1) Filtration Systems

Sand Filtration is widely used for water treatment. But some efficient filtration systems using fibrous materials have been developed. The main purpose of such systems is to significantly reduce the area of filtration process. In a fibrous filtration systems, filtration media is a layer piled up by many number of fiber mass blocks. Periodically filtrated residue on the media are removed by counter washing accompanied by aeration. Fig.9 schematically shows one of noticeable systems, in which filtration is continuously carried out on the inner surface of a rotating drum. The filter media is composed of a double layered satin fabric whose surface is covered by raised micro-fibers of weft yarn. Filtrated particles/trash on the surface are removed into condensed waste water by counter washing. It is especially useful for the treatment of water containing large amount of plankton.

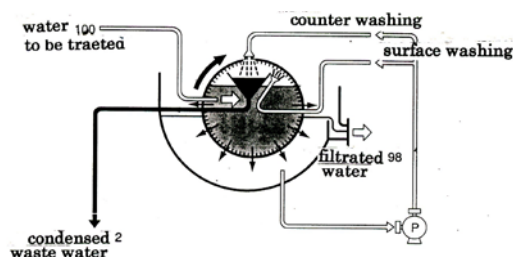


FIG. 9 FILTRATION SYSTEM USING ROTATING DRUM COVERED BY MICRO-FIBER FABRICS

The uses of ultra-filtration(UF), and micro-filtration (MF) membrane hollow fibers for non-bionic waste water treatment have been increased. Large number of hollow fibers are contained as bundle within a module. There are also other forms of UF/MF membrane such as tublar, spiral, and plate. However, hollow fiber form is advantageous in unit compactness and simple handling over the other type of form.

2) Bio-reactive Treatment Systems Using Hollow Fiber

In the case that filter media is a large number of fiber mass blocks sustaining micro-organism, the system can be act as not only a filtration vessel, but also a bio-reaction vessel to reduce BOD of organic waste water. Fig.10 illustrates a bio-reactor system using MF membrane hollow fiber. In the system, large numbers of the fiber modules are dipped in activated sludge aeration tank. Water suction is applied in the hollow part of the fibers. Activated sludge filtrated on the outer surface of the fiber is removed by bubbling caused by aeration. As compared to conventional bio-reactor system, it can be much compacted and the quality of treated water is much higher.

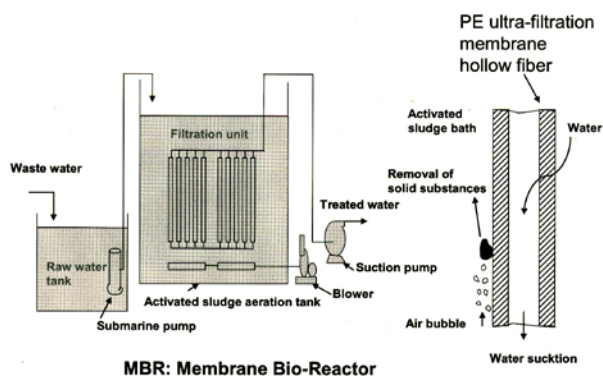


FIG. 10 BIO-REACTOR USING MEMBRNE HOLLOW FIBERS

Reverse Osmosis (RO), and Ultra-filtration(UF) /Micro Filtration(MF) Using Membrane Systems for the Production of Purified Water

1) RO

The active layer of RO membrane is non-porous. By applying pressure higher than RO pressure, water pearmeates into its hollow part through the membrane. Such materials as salt and pyrogen can be rejected at the surface of the layer in membrane. In RO desalination plant, large numbers of RO modules are installed, which contains hollow fiber bundles or spiral membrane. The main end-use of

RO membrane is the production of drinkable water by the desalination of sea water.

2) UF and MF for Water Work

In water work, the requirement to remove pathogenic micro-organism has increased especially in developed countries. Most of UF and MF hollow fibers are very feasible for the requirement.

3) Re-use of Water

In order to efficiently utilize water resource, several technological systems for the re-use of waste water or water recycle have been intensively developed. In these systems, RO, UF, and MF membrane hollow fibers can be effectively utilized according to water quality requirements.

Water Purification by Some Specific Fibers

1) System Using Activated Carbon Fiber

Activated carbon fiber is often used in the combination with UF/MF membrane hollow fiber as a major component of water purifying equipment for drinking water. The main role of activated carbon fiber in the equipment is to remove such substances as chlorinated organic chemicals and smell constituents.

1-4 dioxane which is toxic and contained in the water exhausted from some kinds of chemical plant can not be removed by conventional water treatment methods. Recently an effective treatment system utilizing activated carbon fiber has been developed, in which the substances contained in the water to be treated was vaporized by bubbling and then the vaped substances is introduced into VOC removal systems described later. 1-4 dioxane still remained in the water after the bubbling is almost completely adsorbed by activated carbon fiber bed during its passing through the bed.

2) Photo-catalyst Fiber

A water purification system using conical nonwoven units made of photo-catalyst fiber has been developed. The constituent of the fiber is gradually varied from silica at the core part to TiO_2 (photo-catalyst) at the surface. In the system, , a UV lamp is located at the axial center of the conical unit line. Contaminants in the water are oxidized and degraded by the photo-catalyst under the UV light during water passing through the conical units line. It is effectively utilized to purify the

water of public bath, of spring bath, and of swimming pool.

3) Ion Exchangeable Fiber

There are some kinds of ion exchangeable fiber, which are effective to remove toxic ingredients of heavy metal from water. The fiber made of ion exchangeable polystyrene resin is used for the purification of recycled water from such a source as atomic power plants.

Separation Between Oil and Water

Oil Skimming from Water

The flow-out of oil into sea or river has often caused a serious environmental problem. Oil fences are used in order to limit the area of oil contamination on the water surface. It is typically composed of a) sheet fence made of woven fabric reinforced by belt, b) float made of foamed polystyrene covered by woven fabric, and c) weight for stabilization. Oil floating on water surface can be removed by making use of oil adsorptive fibrous sheet. Its material is usually nonwoven made of PP, kapok or cotton. It takes several kinds of form according to oil removal situation. In case, oil skimming net can be effective to prevent the enlargement of oil contamination area. Oil floating zone can be reduced by simultaneous action of oil removal by the adsorptive sheet attached to net and the enclosure operation of net.

Oil/ Water Separation for Purification

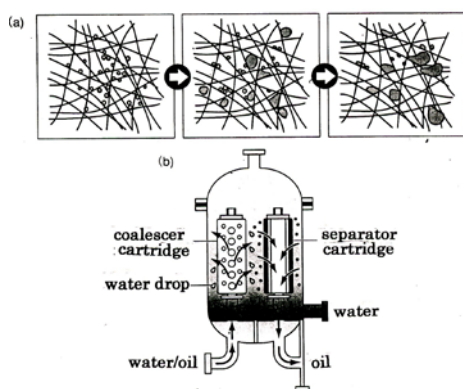


FIG.11 OIL/WATER SEPARATOR (a) PRINCIPLE OF SEPARATION AT COALESCER MEDIUM (b) SEPARATOR TANK WITH COALESCER AND SEPARATOR CARTRIDGE

This item concerns removing small amount of water from oily materials or small amount of oil from water. Fig. 11 is a typical example of the system for the removal. The coalescer cartridge medium is composed of micro-fiber nonwoven felt having very small pore size. Small size of oil particles can quickly coagulate

by the micro-fiber network as schematically shown in (a) of the figure. The separator cartridge is made of membrane, mesh cloth or nonwoven having surface of water repellency. This kind of system is used for such end-uses as the removal of water from air-craft fuel, petroleum products, and the removal of oil from cooling water for chemical plants.

Air Purification

Bag Filter

Bag filter widely used for removal of dust contained in the exhaust gas from several kinds of incinerators is usually made of glass fiber woven fabric or synthetic fiber needle felt or its combination with woven fabric. PPS, m-aramid, poly-imid, poly-tetra-fluoro-carbon are typically used as the synthetic fiber. The dust in exhaust air is caught on the accumulated dust on the surface of bag filter whose shape is cylindrical bag. When the inlet pressure increases up to a settled value by the lay-up of accumulated dust, it is dropped off from the bag surface by counter pulse jet or mechanical vibration. Acid gas and some other harmful gas substances can be also removed by introducing such materials as slaked lime and activated carbon in the bag.

Air Filter

Air filters used for the removal of dust for clean room and office contribute to energy saving by the recycle of conditioned air. The filter medium is usually nonwoven.

With a decrease in the fiber diameter, the removal efficiency of filter is increased, but its back pressure is increased. Removal efficiency is the lowest at 0.05-0.1 μ m of dust particle size, because inertial collision effect for catching dusts within air flow by fiber becomes more significant for larger particle in the range of particle size above 0.1 μ m and diffusion effect is more effective for small particle below 0.05 μ m. Filter medium is usually pleated in the filter of high removal efficiency, because the pleating increases the area of filtration and then can reduce the back pressure of the filter by lowering the velocity of air passing through filter medium.

Electret filter can have higher removal efficiency with comparatively low back pressure by making use of electric static traction force between dust and fiber.

The filter unit whose medium is independently exchangeable after its back pressure increases up to a certain settled value has been developed in order to

save unit frame.

Removal of Volatile Organic Compounds (VOC) and Solvent Recovery

Activated carbon fiber is useful as the key material for i) removal system of VOC and ii) solvent recovery system. In the former system, the honeycomb bed for adsorption is formed by piling corrugated board made of activated carbon paper. The exhaust gas containing harmful substances passes through the main part of the honeycomb and is removed by the adsorption at the honeycomb wall. In the fixed zone of small angle, the adsorbed substances are desorbed by hot air. The air containing condensed harmful substances thus produced is after-treated by much smaller scale system of oxidization or adsorption for solvent recovery. This system is feasible for treating exhaust gas from several kinds of industries such as semiconductor production, LCD production, automobile painting booth, which is of large amount flow of air containing small amount of harmful substances.

In the solvent recovery system, activated carbon nonwoven is wound on a plural of cylinder. Solvent adsorbed by the cylindrical bed is periodically desorbed by steaming. Thus solvent removal can be performed with continuous operation. Advantages of this system are higher quality of recovered solvent and smaller size of system over systems using conventional granular activated carbon, because of its much higher adsorption and desorption rate.

Filter for Dust Exhausted from Diesel Engine

Fig. 12 shows system for removing particles contained in the exhaust gas from diesel engine using felt made of SiC group fiber. The felt is pleated into cylindrical form. Particles filtrated by the filter are burned out at times by electrical heating. Its removal efficiency is more than 95%.

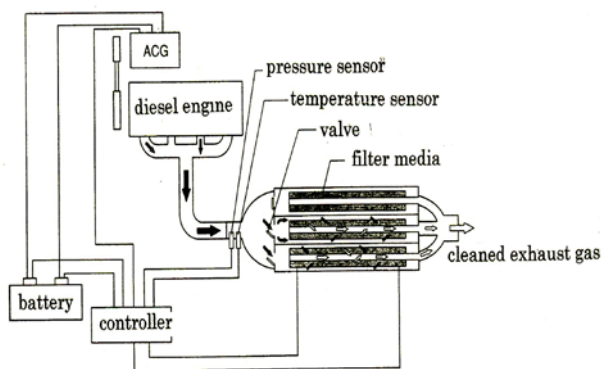


FIG. 12 A SYSTEM FOR REMOVAL OF PARTICLES EXHAUSTED FROM DIESEL ENGINE

Enclosure of Contaminated Substances

Enclosure of Cesium

The most serious problem for atomic power plant disaster is how to effectively enclose cesium 137, because its radio-active ray is gamma ray and its half life is so long as about 30 years. It has been found that prussian blue is one of the most excellent in adsorption characteristics, whose crystal is composed by FE and CN with a certain vacancy. Cesium ion can be easily adsorbed in the vacancy. Cesium ion can be extracted in the form of acid aqueous solution from such substances as soil radio-actively contaminated. The cesium contained in the solution can be effectively enclosed by nonwoven bed sustaining prussian blue.

Insurance for Preventing Contaminated Water Leakage from Final Landfill Site

The bottom layer of final landfill site was usually rubber as the proof for the leakage of contaminated water. But by chance the layer is broken. Now nonwoven made of super water absorbable fiber is often introduced under the rubber layer for insurance to prevent the leakage.

Conclusion

In this article, fibrous technologies contributing to the attenuation of environmental and resource problems are overviewed in the 9 major fields. It is thought that the potential in the market size of these technologies can be more increasing now as a whole. But those who want to be successful in these fields, are at first required to have enough knowledge and information to understand the real technological problems. Further strong ambitious and eagerness are indispensable for them. In this situation, they must fully make use of the advantages of fibrous materials over the other kinds of materials to solving these technological problems.

REFERENCES

- Aoki, Osamu. "Automobile and Textile", published by Sen-I sha, p28, 2004.
- Endoh, Morinobu. Proceedings of Summer Seminar held by The Soc. of Fiber Sci. and Tech., Japan, 2002. http://www.affgc.co.jp/business/industry/consumer_electrics/vip.
- <http://www.Ngk.co.jp/product/nas>, 2012.
- Izuka, Yoshio. J. of The Textile Machinery Soc. of Japan, 64, 101, 2011.

- Kamo, Jun. "Purification Technology for Environment Using Hollow Fibert", Seikei-Kakou 17, p300, 2005.
- Kato, Tetsuo. Handbook of Fibers(Sen-I Binran) p893, 2004.
- Kawakami, Hiroyoshi. Kakou-gijutsu 44, p223, 2009.
- Kawanaka, Naoki. "Fiber and Water",AFMc Seminar Preprints, p17, 2012.
- NEDO, AIST, Pamphlet of Carbon Nano-tube Capacitor, at Nanotech 2011 Exhibition.
- NEDO, AIST, Pamphlet of Adsorption of Radio-active Cesium, at Nanotech 2012 Exhibition.
- Shibutani, Masaki. "Automobile and Textiles" published by SEN-I-Sha, p895, 2004.
- Taiyokogyo, pamphlet of MakMax, 2012.
- Tanaka, Masahisa. Nonwoven Review 15, No2, p1, 2004.
- Yamanaka, Atsuhiko. "Energy Devices and Fibers", AFMc Seminar Preprints, p17, 2009.
- Yoshino, Akira. "Energy Devices and Fibers", AFMc Seminar Preprints, p1, 2009.



Tatsuki Matsuo was born in Japan, in 1934, graduated from Applied Physics of Tokyo Univ. He received Dr. of Engineering, Tokyo Institute of Technology (1968), and Japan Professional Engineer {Textiles}(1999). He was a staff and a manager of Research Institute of Toyobo Co.

Ltd.(1958-1992), then moved to Faculty of Textile Science, Kyoto Institute of Technology as a professor (1992-1998). He was President, The Textile Machinery Society of Japan (1999-2000). And a managing Director of Japan Textile Consultants Center (2001-2005) and a Visiting Professor, Univ. of Leeds (2004-2005) and Head of Textile Institute, Japan Branch (1998-2001).

His major achievements are development of simulation technology for melt and dry spinning process, development of 3-dimensionally crimped hollow fiber, development of activated carbon fiber and its application systems, and development of thermoplastic fiber reinforced composite material.

Major awards he has received are; Prize of Technology from Soc of Japan Polymer Science (1970), Hall of Fame from Akron Univ. Polymer Processing Center (1996), Honary Membership from The fiber Society (2006), and Ward for Distinguished Contribution to Fiber Science and Technology from The Society of Fiber Science and Technology, Japan (2010).